DEVELOPMENT OF A NATIONAL CENTER FOR HYDROGEN TECHNOLOGY

Year 1 – Activity 6.2.3: Development and Demonstration of Hydrogen-Fueled Vehicles for Niche Markets

Topical Report

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DEVELOPMENT OF A NATIONAL CENTER FOR HYDROGEN TECHNOLOGY YEAR 1 –ACTIVITY 6.2.3: DEVELOPMENT AND DEMONSTRATION OF HYDROGEN-FUELED VEHICLES FOR NICHE MARKETS

ABSTRACT

In November 2005, the Energy & Environmental Research Center (EERC), ePowerSynergies, Inc. (ePSI), and Resurfice Corporation teamed to develop, produce, and demonstrate the world's first and only fuel cell-powered ice resurfacer. The goals of this project were:

- To educate the public on the readiness, practicality, and safety of fuel cells powered by hydrogen fuel and
- To establish a commercialization pathway in an early-adopter, niche market.

The vehicle was developed and produced in a short 3-month span. The vehicle made its world debut at U.S. Senator Byron Dorgan's (D-ND) 2005 Hydrogen Energy Action Summit. Subsequently, the vehicle toured North America appearing at numerous public events and conferences, receiving much attention from international media outlets.

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EXECUTIVE SUMMARY

In cooperation with the EERC, ePower Synergies, Inc. (ePSI), a company that develops multimodal transportation systems for communities utilizing clean, sustainable energy systems, and Resurfice, an established manufacturer of Olympia brand ice resurfacer vehicles, teamed to develop, produce, and demonstrate the world's first and only fuel cell-powered ice resurfacer. This niche vehicle has been labeled the "eP-ICEBEAR."

Most ice refinishers are powered by propane-fueled internal combustion engines and typically utilize hydrostatic drivetrains. With these ice refinishers, engine exhaust emissions tend to concentrate near the ice. Propane-powered ice resurfacers have also been identified as the cause of carbon monoxide buildup in inadequately ventilated ice arenas. During 2005 and 2006, four separate evacuation events were caused in North America by these buildups. Although battery and tethered electric units are available, they are expensive and have not always met the needs of ice facilities. Fuel cell-powered hybrid electric vehicles have the potential to ease operator, maintenance, and other issues.

DEVELOPMENT OF A NATIONAL CENTER FOR HYDROGEN TECHNOLOGY YEAR 1 –ACTIVITY 6.2.3: DEVELOPMENT AND DEMONSTRATION OF HYDROGEN-FUELED VEHICLES FOR NICHE MARKETS

BACKGROUND

Most ice refinishers, such as the one shown in Figure 1, are powered by propane-fueled internal combustion engines and typically utilize hydrostatic drivetrains. With these ice refinishers, engine exhaust emissions tend to concentrate near the ice. Propane-powered ice resurfacers have also been identified as the cause of carbon monoxide buildup in inadequately ventilated ice arenas. During the past 30 years, several cases of acute carbon monoxide (CO) poisoning have been reported in North America (1–12) during routine ice resurfacing. Studies from North America and Europe have documented high levels of CO in ice arenas using hydrocarbon fuel-powered ice resurfacers (13–33).

Although battery and tethered electric units are available, they are expensive and have not always met the needs of ice facilities. Fuel cell-powered hybrid electric vehicles have the potential to ease operator, maintenance, air emissions and other issues.

INTRODUCTION

In cooperation with the Energy & Environmental Research Center (EERC) and the U.S. Department of Energy (DOE), ePower Synergies, Inc. (ePSI), a company that develops multimodal transportation systems for communities utilizing clean, sustainable energy systems, and Resurfice, an established manufacturer of Olympia brand ice resurfacer vehicles, teamed to

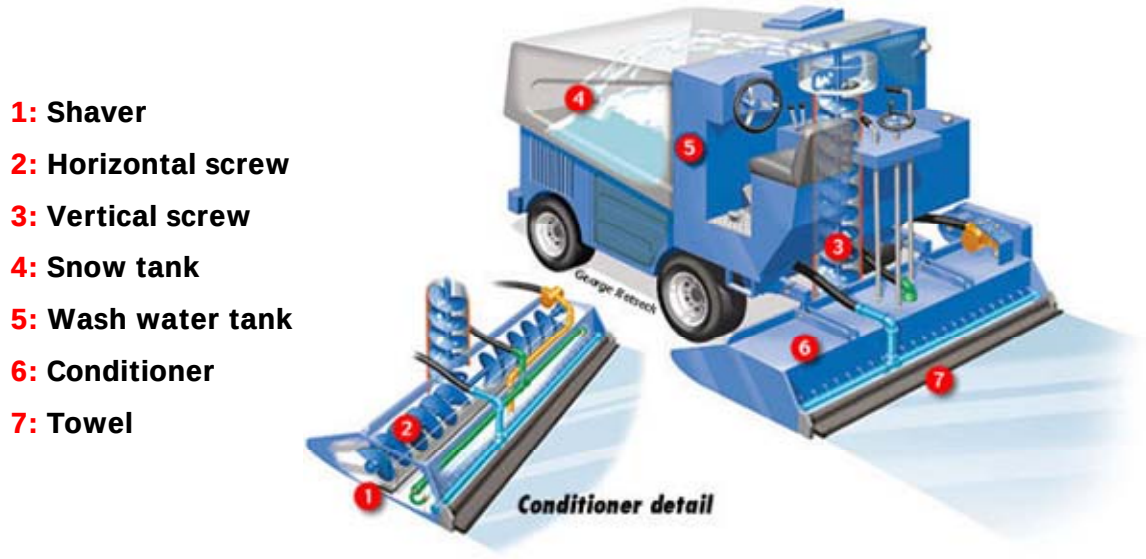

Figure 1. Typical configuration for an ice resurfacer.

develop, produce, and demonstrate the world's first and only fuel cell-powered ice resurfacer. This niche vehicle was labeled the "eP-ICEBEAR."

It was the desire of this team to demonstrate that the technology required to support the hydrogen economy is highly evolved and ready to take hold. It is recognized that infrastructure and public awareness concerns drive the change in inertia required to bring about the change to a hydrogen-based economy — a national interest indicated by President Bush's Hydrogen Fuel Initiative, announced on January 28, 2003. This initiative envisions the transformation of the nation's transportation fleet from near-total reliance on petroleum to steadily increasing use of clean-burning hydrogen.

Because of this required change in inertia associated with a global hydrocarbon-based economy, an alternate approach to mainstreaming hydrogen vehicles is required. Instead of attempting to change the very large automotive transportation sector, fuel cell technology may have a better chance at gaining foothold if niche vehicles such as ice resurfacers and other unique utility vehicles are demonstrated as fuel cell-powered platforms. This is the approach favored by ePSI and other companies interested in making fuel cell technology a vital part of the market.

EXPERIMENTAL METHODS

Scope of Work

The scope of work for this project included designing and building a fuel cell-powered ICEBEAR ice resurfacer, testing and validating said vehicle, and demonstrating the vehicle across North America and Europe.

Design and Build

The project team developed a completely new design for powering such a vehicle, since no such vehicle existed. This work involved electrical and mechanical engineering tasks required to integrate a high-pressure fuel tank, a fuel cell stack and a power storage module into an existing volume within an existing vehicle frame. A power controller to govern use and storage of excess power for later use during peak current draw periods was designed to accommodate the specific duty cycle of the vehicle.

To determine this duty cycle, studies were conducted on actual use of a battery-powered ice resurfacer. Ice rink resurfacing (called a "flood") frequency was measured along with other parameters such as speed and duration of drive at speeds. Determining the total energy required to complete a representative set of floods provided design information to drive sizing of the fuel cell stack, hydrogen fuel tank, and power storage module.

As an adjunct function of this project, an industrial hydrogen refueling station was also designed and built for use on the project. This involved the EERC contracting with Kraus Global, a manufacturer of compressed natural gas dispensers and pumps, to design and build an industrial hydrogen dispenser capable of refueling the ICEBEAR vehicle.

Testing and Validating

Testing and validation of the ICEBEAR vehicle was required to prove functionality and ease of operation. It was also required, initially, to address design issues and troubleshoot systems during the shakedown period.

Demonstration and Public Outreach

Demonstration and public outreach were, in some respects, the primary goals of this project. As such, most of the project effort after the design phase was put into these tasks. Promotion of the vehicle and its hydrogen power aspects was planned, and numerous unplanned exhibition opportunities were utilized as well.

RESULTS AND DISCUSSION

Design and Build

In a short period of 3 months prior to November 2005, ePSI coordinated the design of a fuel cell power system for an Olympia ICEBEAR battery electric ice resurfacer, shown in Figure 2. This work involved significant design challenges including fitting the required fuel cell power system components into a pair of vehicle bays designed for a battery power storage system and designing a governing power control module to route power through a power storage module to govern fuel cell stack activation and deactivation.

Figure 2. Olympia brand ICEBEAR ice resurfacer.

ePSI worked closely with Resurfice Corporation to integrate the fuel cell-based electric drivetrain into an existing battery-powered vehicle design. ePSI contracted with a fuel cell manufacturer, Nuvera, to provide a 5-kW fuel cell stack. This stack is shown in both Figures 3 and 4. A fuel cell integrator, HyMotion, was contracted to integrate the Nuvera fuel cell stack with a custom power controller (also shown in Figure 3) and a custom battery-based power storage unit. ePSI, HyMotion, and Resurfice worked closely to accomplish the integration of all components into the small volumes existing in the ICEBEAR vehicle (shown in Figure 5 and Figure 6) that were previously used as battery compartments.

The EERC contracted with Kraus Global to design and manufacture an industrial hydrogen dispenser (shown in Figure 7) capable of filling the eP-ICEBEAR tank from either a single-cylinder high-pressure hydrogen source or a cascade (multicylinder) source. This dispenser was installed at the EERC but was capable of being relocated to any demonstration venue with minimal effort.

Testing and Validating

Testing and validation of the vehicle design and function was accomplished by Resurfice, HyMotion, and ePSI at a facility owned by the University of Ottawa. Charging of the power storage module via the fuel cell stack was verified. Drive function of the vehicle was also accomplished by performing several ice resurfacing operations at the University of Ottawa ice arena.

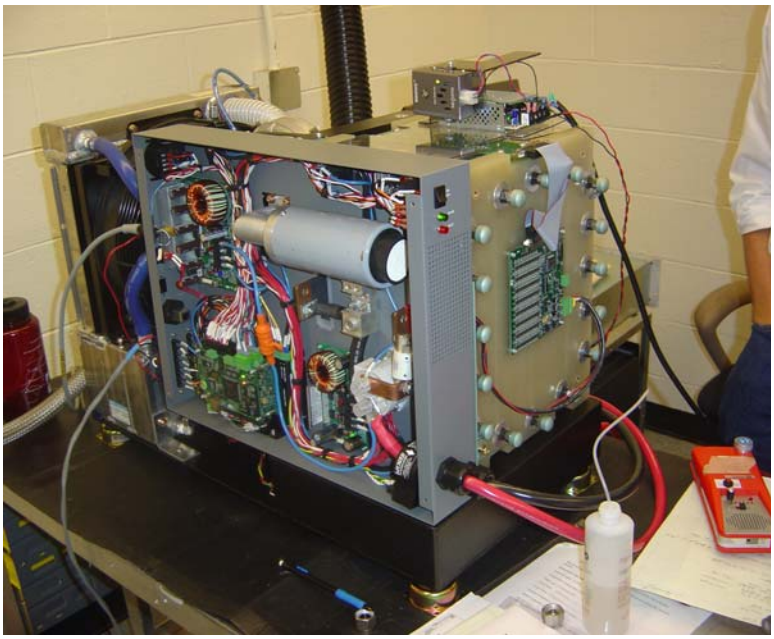

Figure 3. Nuvera fuel cell stack (with mounted HyMotion power control module).

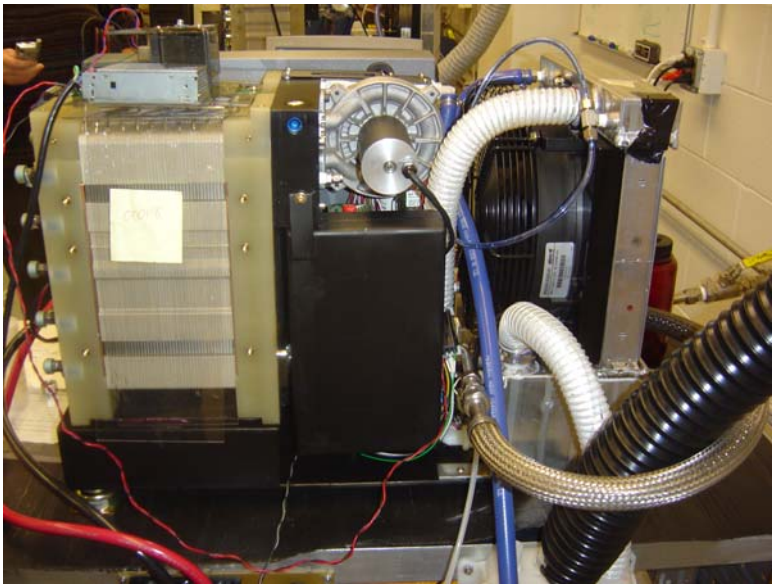

Figure 4. Nuvera fuel cell stack (left) with radiator.

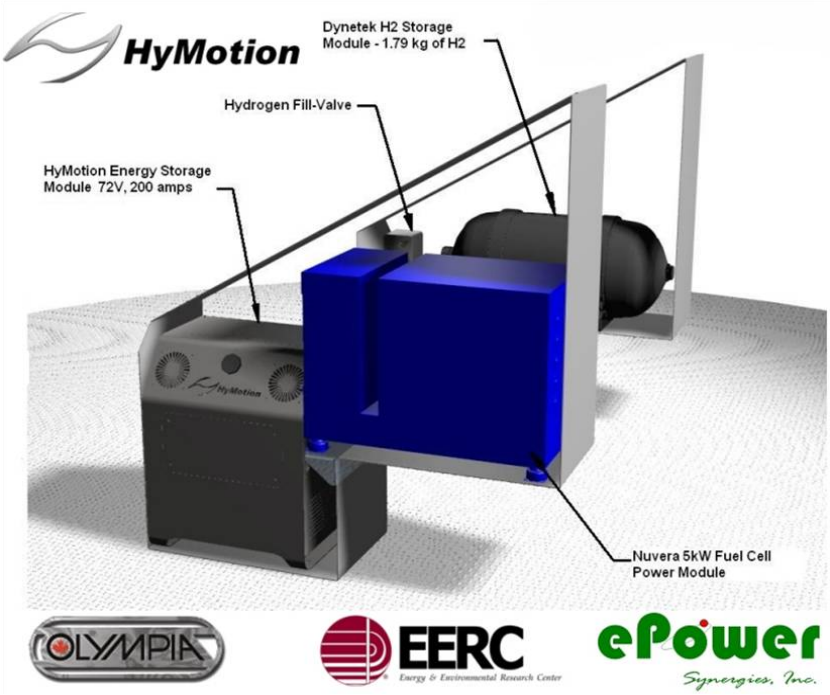

Figure 5. Fuel cell power system in power storage bays of the ICEBEAR vehicle.

Figure 6. Fuel cell power system as installed in the ICEBEAR vehicle.

Figure 7. Industrial hydrogen fuel dispenser.

Fuel-filling function was verified at low pressure (<1000 psi) at the University of Ottawa facility and at high pressure (5000 psi) at the EERC using the EERC's industrial hydrogen fuel dispenser. This function worked perfectly.

Design problems with the vehicle power control system were discovered during extended use of the vehicle. It was discovered that the standard hydraulic system used in the ICEBEAR vehicle put too much of a demand on the 5-kW fuel cell system, causing it to deplete energy reserves frequently. The vehicle had to be idled or manually charged by an external battery charger more frequently than planned because of the higher-than-expected demand from the vehicle hydraulic system. Potential solutions to this problem include replacing the hydraulics (which require a pump system that runs inefficiently) with electromotive actuators, increasing

the size of the fuel cell power plant, or reconfiguring the power controller logic to more efficiently run the existing equipment and balance power demand with power availability. These problems are quite standard for one-of-a-kind prototypes such as this vehicle. It is expected that all problems could be addressed in another vehicle design revision.

Demonstration and Public Outreach

The eP-ICEBEAR was toured around the continent of North America to fulfill its mission of serving as a herald of the hydrogen economy. During this extensive tour, it received substantial attention from many media sources, both print and television.

Tour History

The vehicle was exhibited in its debut at the November 2005 Hydrogen Energy Action Summit coordinated by Senator Byron Dorgan (D-ND). A photo of the vehicle on display at this venue is shown in Figure 8. Major players in hydrogen technology were in attendance at this conference, including Ballard (fuel cells), AeroVironment (hydrogen-powered unmanned aerial vehicles), Air Products & Chemicals Co. (hydrogen fuel and dispensing stations), Kraus Global (hydrogen dispensing stations), Dynetek (high-pressure hydrogen storage) and others. Because of the high caliber of this summit, the vehicle received much attention from industry and media.

During the Hydrogen Energy Action Summit, the vehicle was also demonstrated on-ice at a local ice arena in Grand Forks, North Dakota. Purpur Arena was the maiden demonstration for the eP-ICEBEAR. During this demonstration (shown in Figure 9), professional ice resurfacer drivers were given the opportunity to put the vehicle through its paces and give feedback on its performance. Feedback was overwhelmingly positive. The drivers, who normally drive propane-powered Zamboni ice resurfacers, were pleased with the quietness and on-ice handling of the eP-ICEBEAR. They also liked the fact that no hydrocarbon emissions were present.

Figure 8. World debut of eP-ICEBEAR at Senator Byron Dorgan's (D-ND) 2005 Hydrogen Energy Action Summit (EERC, Grand Forks, North Dakota).

Figure 9. eP-ICEBEAR on-ice demonstration at Purpur Arena (Grand Forks, North Dakota).

Next, the vehicle was exhibited at the Electric Drive Transportation Association (EDTA) Conference and Exposition in Vancouver, British Columbia, in December 2005. Here, the vehicle was displayed alongside other cutting-edge hydrogen-powered vehicles from Toyota, Lexus, Ford, and Honda. A photograph of the static display at the EDTA Expo is shown in Figure 10.

In July 2006, the eP-ICEBEAR was exhibited at the North Dakota State Fair in Minot, North Dakota (Figure 11). This was a true public education venue, giving the general public a chance to learn about the vehicle and about fuel cells and the coming hydrogen economy. Approximately 500 visitors stopped to see the eP-ICEBEAR at this venue.

The North Dakota State Fair was followed immediately by the Minnesota State Fair in St. Paul, Minnesota, in August 2006. A highlight of this exhibition was Governor Tim Pawlenty (R-MN) investigating the vehicle for himself and stopping for a photo opportunity (see Figure 12) atop the driver's seat of the vehicle. It is events such as this that gain additional attention from media outlets, further educating the public as to the availability of hydrogen fuel technology today.

In September 2006, another on-ice demonstration was held in Davenport, Iowa, at the Quad-Cities Sports Center (shown in Figure 13). Here, a group of about twelve ice resurfacing experts gathered to assess the eP-ICEBEAR and provide feedback on its design and operability.

Figure 10. eP-ICEBEAR exhibition at the Electric Drive Transportation Association Expo and Conference (Vancouver, British Columbia).

Figure 11. eP-ICEBEAR exhibition at the North Dakota State Fair (Minot, North Dakota).

Figure 12. Governor Tim Pawlenty (R-MN) on the eP-ICEBEAR during exhibition at the Minnesota State Fair (St. Paul, Minnesota).

Figure 13. On-ice demonstration of eP-ICEBEAR in Davenport, Iowa.

Media Attention

Table 1. ePICEBEAR Media Coverage (November 2005 – Present)

Date	Headline	Media Organization/Publication	Journalist, Author, or Source	Type
11/4/2005	ePower Synergies announces world's first fuel cell-powered ice resurfacer	ePower Synergies	EERC	Press Release
11/4/2005	World's first fuel cell-powered ice resurfacer to be unveiled at the EERC	EERC	Derek Walters	Press Release
11/7/2005	Hydrogen Summit and eP-ICEBEAR unveiled	KVLY-TV 11	Neil Carlson	Television
11/7/2005	Hydrogen Summit and eP-ICEBEAR unveiled	WDAZ-TV	James Degelder	Television
11/7/2005	Hydrogen Summit and eP-ICEBEAR unveiled	KNOX 1310	Doug Barrett	Radio
11/7/2005	Hydrogen Summit and eP-ICEBEAR unveiled	North Dakota Public Radio	Todd McDonald	Radio
11/7/2005	World's first fuel cell-powered ice refinisher takes the ice	Upper Midwest Hydrogen Initiative	Staff Report	Press Release
11/7/2005	Conference highlights use of hydrogen	FuelCellWorks	InForum	Online Article
11/7/2005	Conference features hydrogen-powered "ICEBEAR"	The Associated Press State & Local Wire	Dave Kolpack	Online Article
11/7/2005	Conference features the new hydrogen-powered "IceBear"	Devils Lake Daily Journal	Staff Report	Newspaper Article
11/7/2005	Conference highlights use of hydrogen	Fargo Forum	Patrick Springer	Newspaper Article

Continued . . .

Table 1. eP-ICEBEAR Media Coverage (continued)

Date	Headline	Media Organization/Publication	Journalist, Author, or Source	Type
11/7/2005	ICEBEAR featured at hydrogen conference	Valley City Times-Record	Staff Report	Newspaper Article
11/8/2005	Conference features hydrogen-powered "ICEBEAR"	Canoe Network, CNEWS	Staff Report	Online Article
11/8/2005	Conference features hydrogen-powered "ICEBEAR"	Canadian Television (CTV.ca)	Associated Press	Online Article
11/8/2005	Ice-resurfacing vehicle runs on hydrogen	Bismarck Tribune	Dave Kolpack	Online Article
11/8/2005	Fuel cell ice cleaner sweeps forum	Fuel Cell Today	Grand Forks Herald	Online Article
11/8/2005	Hydrogen ice cleaner sweeps forum	Grand Forks Herald	David Dodds	Newspaper Article
11/8/2005	Hydrogen-powered ice resurfacer unveiled	Bismarck Tribune	Dave Kolpack	Newspaper Article
11/8/2005	Conference features hydrogen-powered "ICEBEAR"	Dickinson Press	Staff Report	Newspaper Article
11/8/2005	Hydrogen-powered "ICEBEAR" featured at UND conference	Williston Herald	Dave Kolpack	Newspaper Article
11/8/2005	Hydrogen-powered ice-resurfacing machine featured at conference	Minot Daily News	Staff Report	Newspaper Article
11/10/2005	World's first fuel cell-powered ice refinisher takes the ice	Upper Midwest Hydrogen Initiative	Staff Report	Online Article
11/10/2005	World's first fuel cell-powered ice resurfacer unveiled at the EERC	McVille Messenger	Staff Report	Newspaper Article
11/12/2005	These machines never die, they just resurface with new technology	The Globe and Mail	Zamboni.com	Online Article

Continued . . .

Table 1. ePI-CEBEAR Media Coverage (continued)

Date	Headline	Media Organization/Publication	Journalist, Author, or Source	Type
11/13/2005	Conference features hydrogen-powered "ICEBEAR"	FuelCellWorks	Staff Report	Newsletter Article
11/18/2005	Zamboni gets a hydrogen upgrade	Dakota Student	Erik Edison	Newsletter Article
12/6/2005	Fuel cell-powered ice refinisher debuts	Earthtoys Alternative Energy Library	ePower Synergies	Online Article
12/13/2005	Fuel cell-powered ice refinisher debuts at the Electric Drive Transportation Association (EDTA) exhibition.	FuelCellWorks	Staff Report	Online Article
12/14/2005	Fuel cell-powered ice refinisher arrives at the home of 2010 Winter Olympics	Fuel Cell Today	Staff Report	Online Article
12/15/2005	World's first fuel cell-powered ice refinisher takes the ice	Consulate General of Canada in Minneapolis	Staff Report	Online Article
12/15/2005	Fuel cell-powered ice refinisher arrives at the home of 2010 Winter Olympics	Migas-Indonesia Online	Staff Report	Online Article
12/18/2005	Fuel cell-powered ice refinisher debuts	Iran Daily	Staff Report	Magazine Article
12/19/2005	Zero-emissions ice resurfacer runs on fuel cells	Renewable Energy Access	Staff Report	Online Article
12/19/2005	Green ice	ESPN Magazine	Brett Zarda	Magazine Article
January 2006	World's first fuel cell-powered ice resurfacer	Advanced Fuel Cell Technology	Staff Report	Magazine Article
January 2006	First-ever hockey rink resurfacer FCV debuts	Fuel Cell Industry Report	Staff Report	Newsletter Article

Continued . . .

Table 1. ePICEBEAR Media Coverage (continued)

Date	Headline	Media Organization/Publication	Journalist, Author, or Source	Type
1/20/2006	From hydrogen ICEBEAR to future EV communities	EVWorld.com	Bill Moore	Online Article
February 2006	"ICEBEAR" will showcase hydrogen fuel technology	UND Dimensions	Juan Pedraza	Newsletter Article
2/3/2006	EERC hydrogen projects	KXLO-Radio	Nick St. Clair	Radio
5/23/2006	Cleaner sweep	Quad-City Times	Kay Luna	Online Article
5/23/2006	The ePICEBEAR	ePower Synergies	Staff Report	News Release
5/26/2006	Environment worries put on ice	The Dispatch and The Rock Island Argus	Jonathan Turner	Newspaper Article
5/26/2006	ICEBEAR most recent option developed by ePower Synergies	Quad-Cities Online	Jonathan Turner	Online Article
5/26/2006	ePower Synergies ICEBEAR story	KWQC-TV	Staff Report	Television
7/18/2006	Hydrogen vehicle showcase comes to North Dakota State Fair	Westhope Standard	Staff Report	Newspaper Article
7/20/2006	Hydrogen vehicle showcase begins tomorrow at ND State Fair	EERC	Derek Walters	News Release
7/21/2006	Hydrogen: The energy source of the future – Now	EERC	Derek Walters	News Release
7/22/2006	State fair to feature hydrogen vehicles	Fargo Forum	Staff Report	Newspaper Article
7/22/2006	Hydrogen vehicle showcase comes to North Dakota State Fair	Mayville, Traill Co. Tribune	EERC	Newspaper Article
7/24/2006	Hydro showcase	Grand Forks Herald	Staff Report	Newspaper Article
Fall 2006	The ePICEBEAR, world's first fuel cell-powered ice resurfacer	Advanced Technology Environmental Education Center	Staff Report	Newsletter Article
September 2006	Hydrogen vehicles featured at ND State Fair	Prairie Business	Staff Report	Magazine Article

CONCLUSION

The eP-ICEBEAR succeeded in its mission to educate the public about the state of hydrogen fuel technology. It toured North America, was seen by estimated thousands of people, and received impressive media attention internationally.

One of the difficulties in bringing about the hydrogen economy is public ignorance on the subject. Projects like this one help to overcome that ignorance.

The vehicle performed well, but design problems were discovered during extended use of the vehicle. It was discovered that the standard hydraulic system used in the ICEBEAR vehicle put too much of a demand on the 5-kW fuel cell system. Potential solutions to this problem include replacing the hydraulics (which require a pump system that runs inefficiently) with electromotive actuators, increasing the size of the fuel cell power plant, or reconfiguring the power controller logic to more efficiently run the existing equipment and balance power demand with power availability. These problems are quite standard for one-of-a-kind prototypes such as this vehicle. It is expected that all problems could be addressed in another vehicle design revision. Because the goal of this project was not production of a refined, commercially ready vehicle, these design modifications were not pursued.

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